MICRO-IMAGER for PLANETARY SURFACE EXPLORATION

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The versatility of the 3-D technique manufactured by 3D PLUS (start-up launched on October 1995 by the people which developed this technique at Thomson-CSF), permits to stack any kind of components from the identical devices (memory modules) to the heterogeneous components (micro-camera, micro-systems).

During the "Mars Exploration Study Team" (MEST) and the assessment of future Martian missions (Marsnet and InterMarsnet), it was identified that the availability of miniature ruggedised cameras, able to operate in an extended temperature range, was highly desirable. This interest was confirmed recently in the Mars Express assessment as well as for other planetary missions such as the Rosetta Surface Science Package, EuroMoon and Smart-1. The 3D packaging technology (also called MCM-V) developed by Thomson-DOI in the early 90's appeared to be the European technology capable to reach the objective of developing a micro-camera of few tens of gram within a reasonable cost envelope.

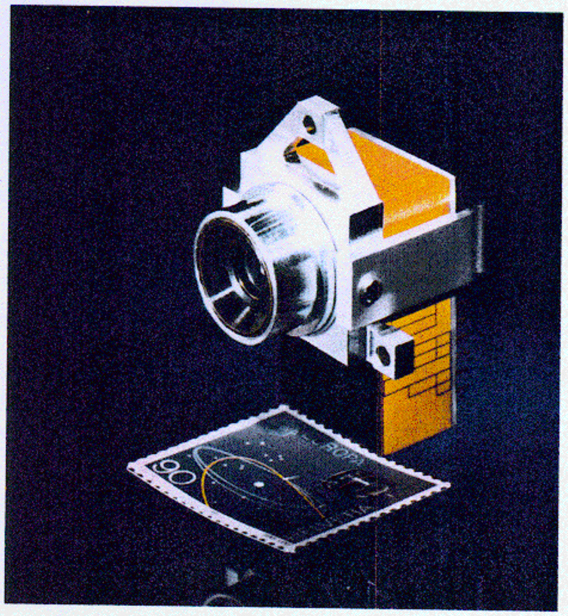

Figure 1 : Picture of the micro-imager prototype

To show the feasibility of such a miniaturized solution, CSEM (Switzerland) has developed, in collaboration with Thomson-CSF (France) and 3D-Plus (France), a prototype of a digital micro-imager based on a microsystem approach. This project, initiated in the frame of the Technological Research Programme of ESA, aims for planetary missions such as Mars, Moon or comet surface exploration. This development is based on the possibility of using electronic components and assemblies at temperatures out of - and in particular below - standard commercial, industrial and military ranges.

The possibilities offered by the most recent microsystem technologies significantly improve resolution, mass and power consumption of imaging systems and are therefore of great interest for space science missions. For instance, receiving high-resolution images of the Mars surface could allow the detection and exploration of sedimentary layers where microfossils may be found.

The micro-imager is composed of three parts, the optics, the opto-mechanical interface, and the electronics. The electronics is packaged in a 3D-stack multi-chip module manufactured by 3D-Plus, and the sensor used is a 1024x1024 pixels CCD chip supplied by Thomson-CSF. High integration is obtained by including the sensor in the 3D packaging, and the mechanical support for the optics was designed in order to minimize mass, taking into account vibration stress during launch and thermal constraints during the missions [+50 to -150 ºC]. Lightness (35 g including optics, opto-mechanical interface and electronics) and compactness of the micro-imager, as well as its low-temperature behaviour, makes it a very cost-effective solution for resource-critical missions.

Electronics

Functionalities and objectives

The camera was designed to deliver then1024x1024 pixels image data at the rate of 10 Mbit/s, coded on 10 bits, driven by an external clock running at 10 MHz.. Integration time and camera control is done through a serial link, minimising the number of wires needed to connect the camera.

The integration time of camera can be programmed from 0 to 655.35 ms in steps of 0.01 ms. Once an image has been taken, it is stored in a memory bank an can then be downloaded at whichever transfer rate is appropriate. The 10 Mbit/s output uses a simple synchronous "Data/Strobe" protocol whereas the 57600 baud output is a simple asynchronous serial link. Both outputs share the same RS422 lines and are software programmable. For ease of use and testing, the camera is programmed and activated via the same 57600 bauds serial link. This allows the camera to be directly connected to any desktop PC.

Electronics schematics

The electronics of the camera includes a TH 7888 1k x 1k CCD image sensor, the type of which was driving the whole concept of the electronic acquisition chain.

Aiming at reduced weight as well as low power consumption, the electronic schematic is designed with a limited number of components. Thanks to the compactness of the final envisioned structure, connections are designed very short, with low line resistances and inductances, resulting in a low level of interferences, and allowing to limit the number of decoupling capacitors. Electronic active components are selected to be purchased either in micro-case (SMT) or in die form, in order to keep the whole 3-D assembly very thin. A particular attention was paid to the routing process of the various connections and in the placing of each electronic part, in order to get a coupling free analog video signal down to the video board level.

A 16 Mbit DRAM is included to allow for a high bit storage density and, to further reduce the numbers of chips, the DRAM controller has been included in the camera control FPGA.

Camera architecture

The electronic schematic are sliced in 6 Printed Circuit Boards :

- CCD board. Based on TH 7888 frame transfer CCD, with a dedicated packaging suited to be incorporated in the 3-D technology.
- CCD driving interfaces and CCD output buffering board, based on ICL circuits.
- CCD video signal sampling and A/D conversion board. This processing board includes two twin circuits : a Correlated Double Sampler TH 7982, and a A/D converter TS 83510, designed for a direct coupling.
- CCD clocks generator board, based on an Altera FPGA.
- I/O and control board, including a 16Mbit DRAM for image storage, RS-422 drivers for the serial links and an Actel FPGA for camera control and data throughput.
- Electrical connecting board

Electronic schematic validation

In order to validate the electronic design, a mini-camera breadboard was built, on the basis of the selected components, and following the described architecture. The test concluded in the validation of the design approach and simulations, both at room temperature, and down to -100 °C.

CCD Packaging

Functionalities and objectives

This packaging is wanted as the upper layer of the 3-D assembly, in order to keep the whole package as thin as possible. The following functionalities are then required from this package :

- to protect the image sensor, as a window of a standard CCD package;
- to serve as the mechanical and optical reference of the ceramic package, like in a standard CCD package;
- to be compatible with the 3-D technology, i.e. to allow lateral connections through the external conductive layers of the 3-D package, to be merged with the other layers during the 3-D coating process, including thermal, chemical and mechanical compatibilities.

Packaging technique

A specific packaging technique was developed, involving mechanical reference transfer, convenient protecting the CCD, wire bonding, and keeping the optical reference (the centre of the CCD optical sensitive plane) in direct relationship with the external optical transparent face plate.

The electronic components (bare die and packed die) of the micro-imager are vertically interconnected with the MCM-V technique. This 3-D technique was developed at Thomson-CSF from 1988 on, and is now manufactured by 3D Plus by the same team. 3D Plus has been launched in 1995 and is involved in numerous space missions. The 3D technique is based on chip-on-flex, test and burn-in for each level, stacking, moulding, cutting, plating and laser etching.

In order to have a very good thermo-mechanical behaviour at low temperatures, a double "sandwich" technique has been used :

- The CCD is sandwiched between two sapphire substrates,

- The assembly (CCD + electronics) is itself auto-compensated by a third layer of sapphire at the bottom of the 3D module.

This structure allows to keep the CCD along a neutral plan of the assembly. For the external connections, pins (Pin Grid Array technique) are used to interconnect several micro-imagers via a flex PCB, the connection PGA / flex being well known and very strong.

Opto-mechanical Design

One of the most critical aspects for the realisation of the micro-imager was the integration of the optics with the CCD sensor and electronics package. The crucial question was : how to position and hold the optics regarding the CCD focal plane. The high positioning specifications, has constrained a new concept to answer the design requirements, such as vibrations (Ariane V launch), wide temperature ranges in particular at low-temperature (-150°C, +50°C), lowest mass as possible (each gramme is important). Putting together all this tough requirements, a concept and design was realised followed by the manufacturing of the mechanical parts.

The idea consists of using the sapphire plate protection of the CCD as the mechanical reference. Three blind holes are machined in the sapphire plate and three pins are inserted in the frame-holder. This combination allows to define and hold the relative position of the optics with respect to the CCD focal plane. In order to maintain the frame-holder on the top of the electronics cube along the z-optical axis, a belt has been designed. The stress along the z-optical axis is applied by the frame-holder on the surface of the sapphire, so the three pins only receive x and y axis stresses. This belt is in fact a preload spring dimensioned for launch vibrations and thermal contraction-dilatation of the cube. Finite elements calculations have been made and show the good behaviour of the micro-imager during the environmental stresses.

Deep space missions are by nature very constrained in term of available mass and power within harsh environmental conditions. The developed microcamera can then be considered as a 'mission enabling technological element' , that is an element which makes that a mission is simply feasible or at least that its scientific return is greatly improved compared to what could be achieved using standard technology.

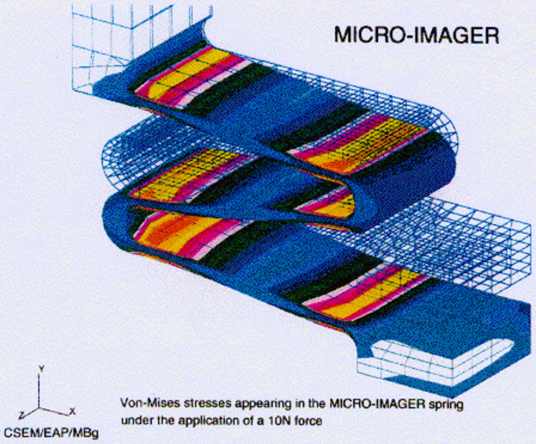

Figure 2 : Stress analysis of preload spring

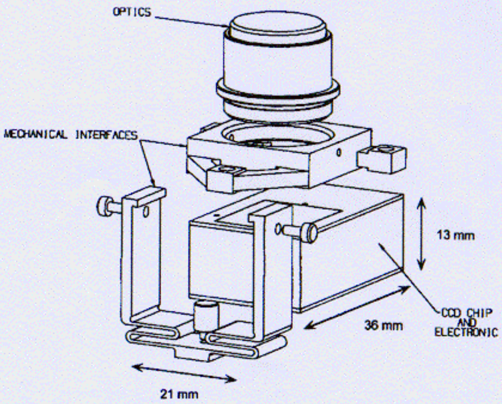

Figure 3 : Exploded view of the micro-imager